U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

2020 SETO PEER REVIEW

# High-Temperature Thermal Systems: Part 2

## New Materials Enable New Behavior

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Contracted to US Department of Energy

# High-Temperature Thermal Systems: Part 2

## A Diversified Portfolio

- Alternative Markets and Opportunities

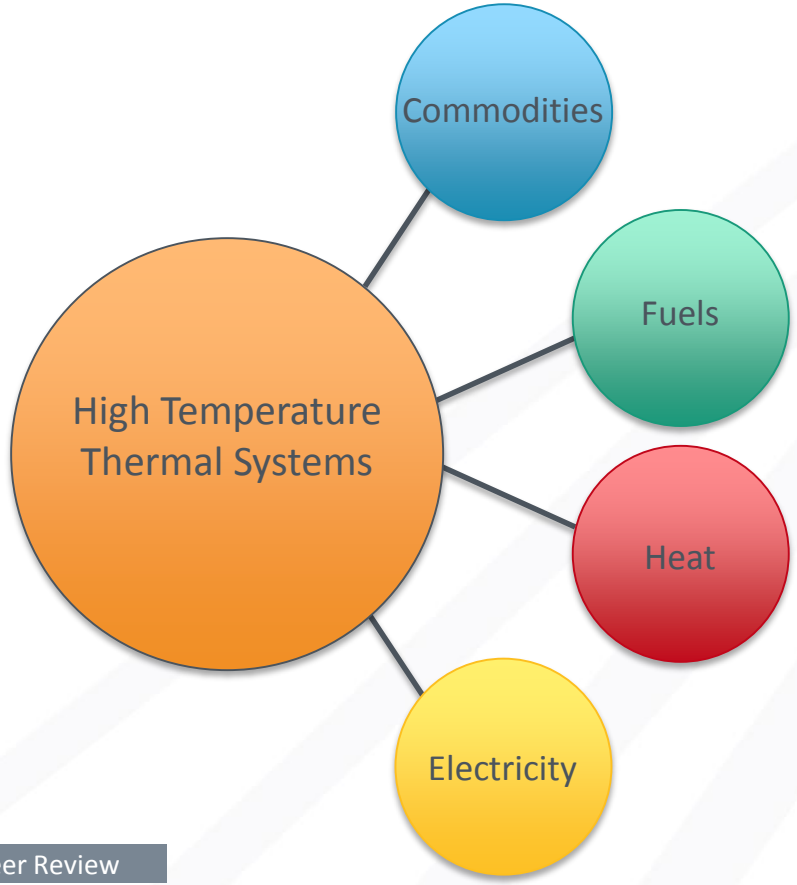
## Materials and Components

- Thermal Energy Storage - Emphasis on Chemical and Latent
- Receivers and Heat Exchangers - Emphasis on Non-Metals and also on Additive Manufacturing

## A Long-Term Investment

- Thermochemical Energy Storage
  - 2013 CSP ELEMENTS --> Present Day: Echogen and Southern Research Institute
- Latent Energy Storage
  - 2013 LPDP --> Present Day: Argonne National Lab
- Solar Selective Coatings
  - 2012 CSP SunShot --> Present Day: Dartmouth University
- Heat Exchangers
  - 2012 CSP Sunshot --> Present Day: Purdue

# Diversified Portfolio: Alternative Markets/Opportunities




Ammonia

Green Hydrogen

1,000+°C Process Heat

Pumped Thermal Storage

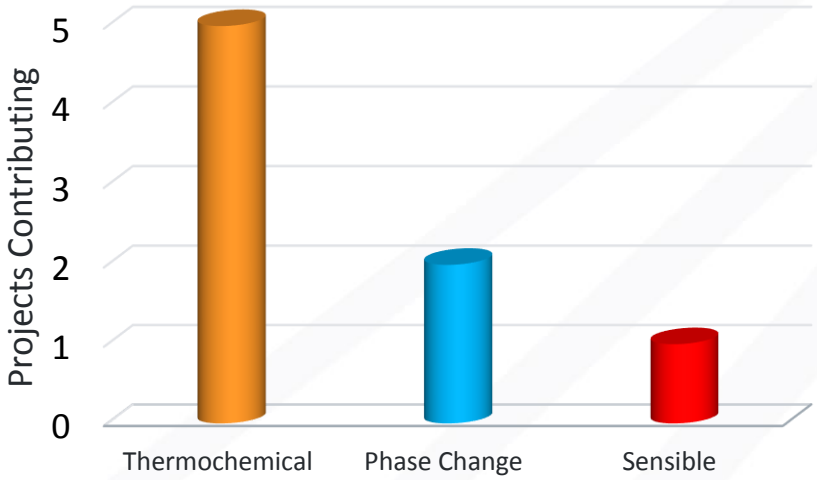
Require new materials and components

# Materials and Components

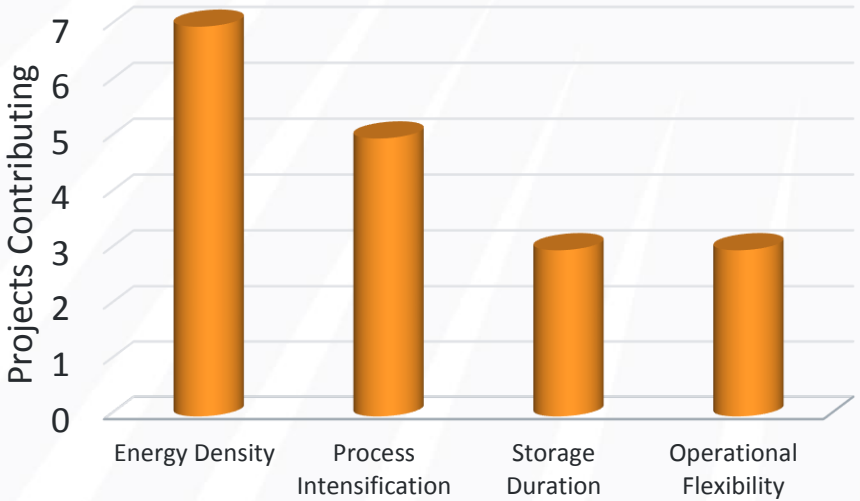
- Thermal Energy Storage (TES)

~8 Projects on time scales longer than Gen3

Different Storage Types…




Focusing on...

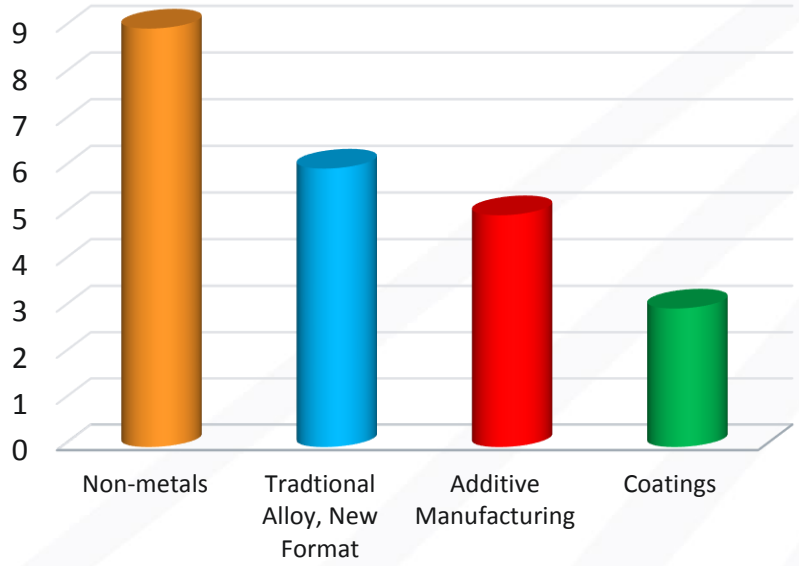


# Materials and Components

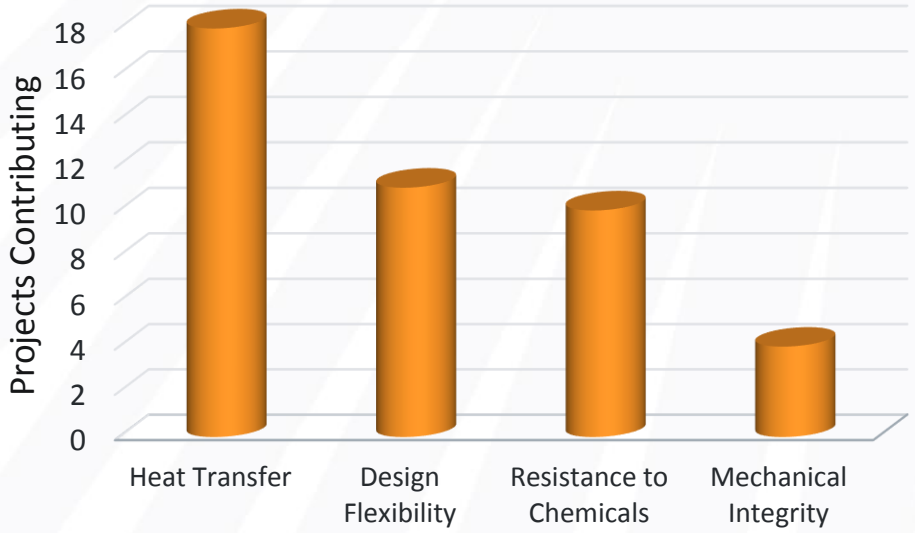
- Receivers and Heat Exchangers

~18 projects on time scales longer than Gen3

Different Strategies…



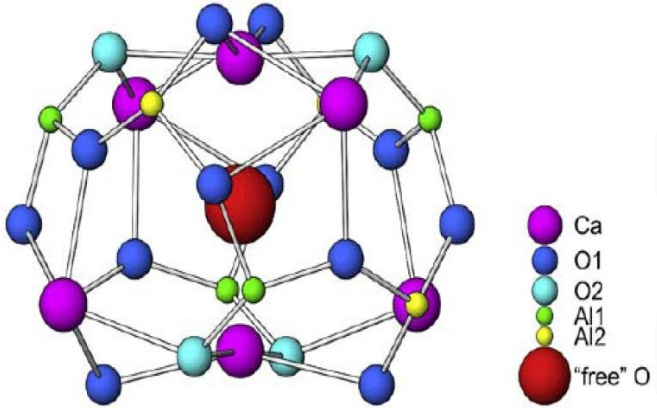

Focusing on…



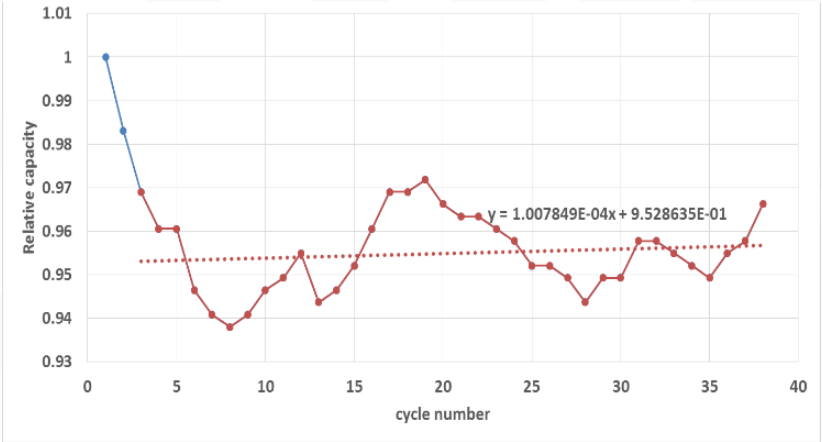
# A Long-Term Investment: Thermochemical Energy Storage

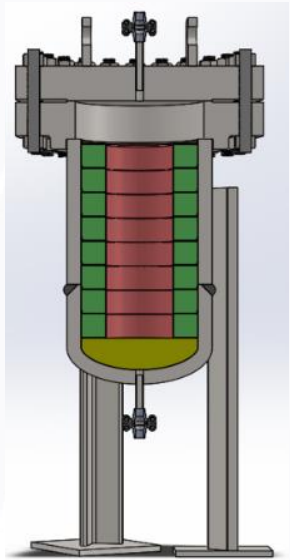
Southern Research Institute + Echogen: $MgCO_3$ + Direct Contact $scCO_2$

1. Develop Figures of Merit: Capacity; Endurance; Manufacturability; Cost
2. Invest Over Time: 2013 CSP ELEMENTS-->2015 CSP APOLLO-->2017 T2M 3
3. Capture Innovation




Structure of $O^{2-}$ containing Ca-Al-oxygen framework mayenite



# A Long-Term Investment: Latent Energy Storage

Argonne National Lab: Salt-Infiltrated Expanded Natural Graphite Foam

1. Develop Figures of Merit: Capacity; Endurance; Manufacturability; Cost
2. Invest Over Time: 2013 LPDP-->2015 CSP APOLLO-->2019 Tech Commercialization Fund
3. Capture Innovation

- Modular
- Hermetically sealed – limits corrosion problems
- Current costs high due to foaming processes

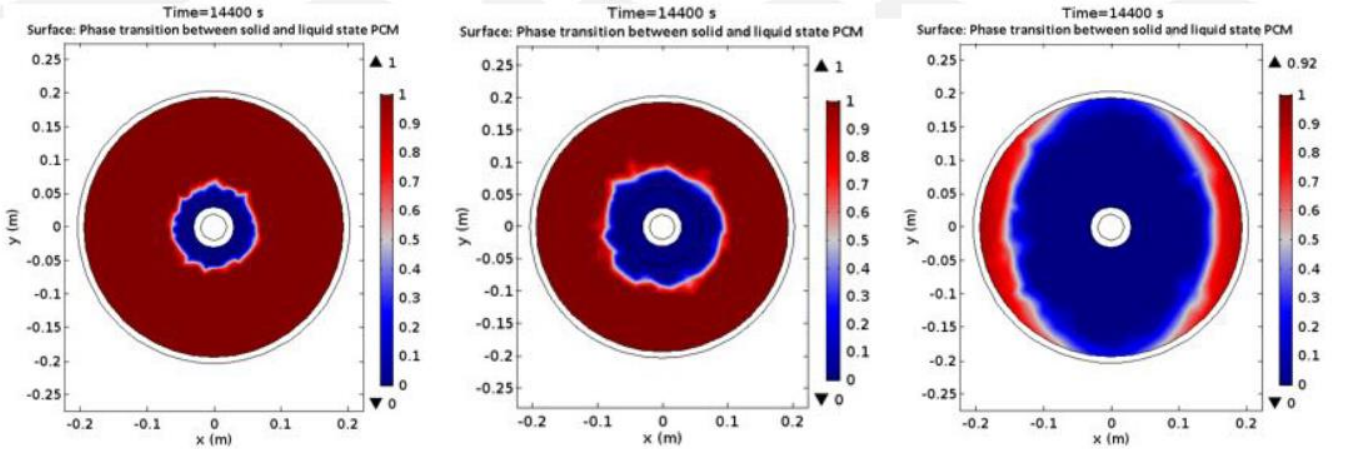
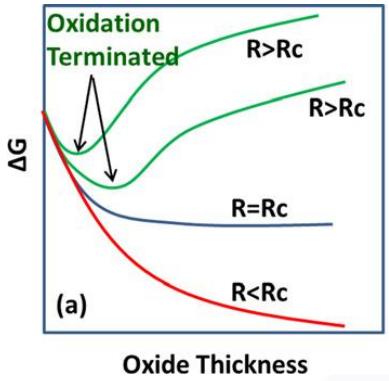


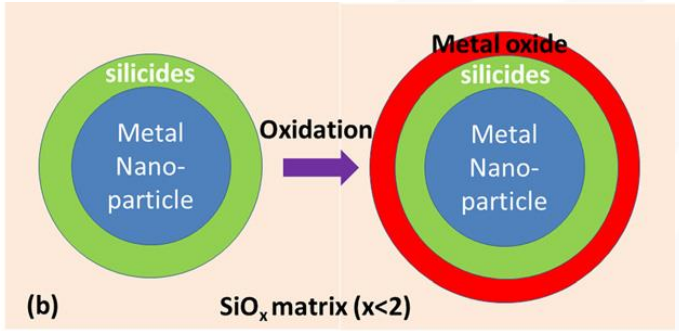

**Figure 2-22.** Heat transfer performances in the three types of LHTES configurations during the discharging process (cross-section view at the middle of the LHTES systems)

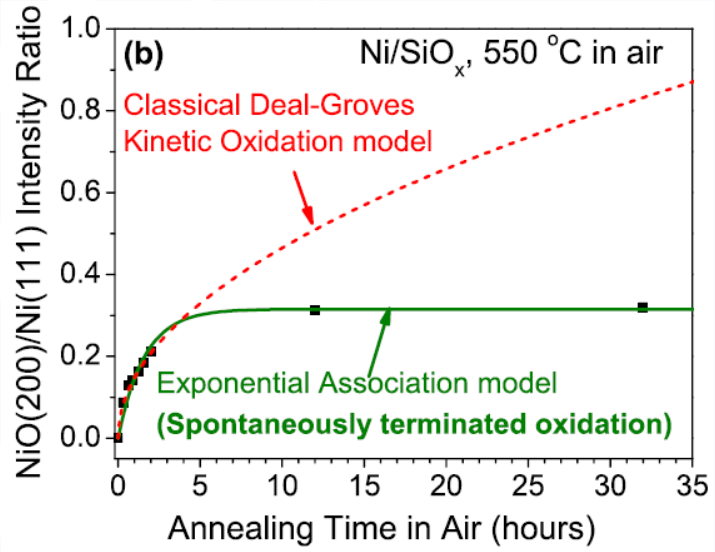
# A Long-Term Investment: Solar Selective Absorbers

Dartmouth University: Thermodynamically Stable Synthesize-in-Place Nanoparticle Coatings

1. Develop Figures of Merit: Optical Selectivity; Endurance; Adhesion; Cost
2. Invest Over Time: 2012 Sunshot-->2013 LPDP-->2015 CSP APOLLO/SuNLaMP-->2018 FY18 FOA
3. Capture Innovation

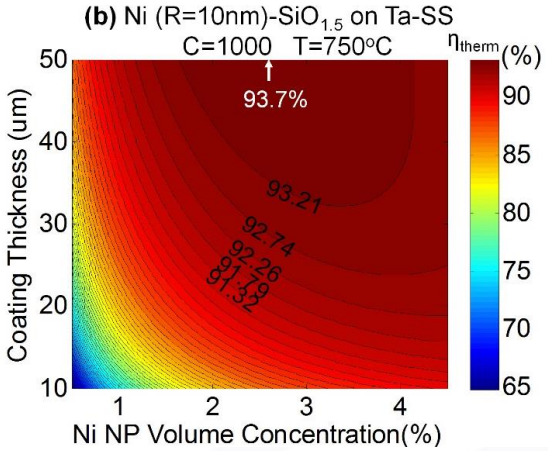


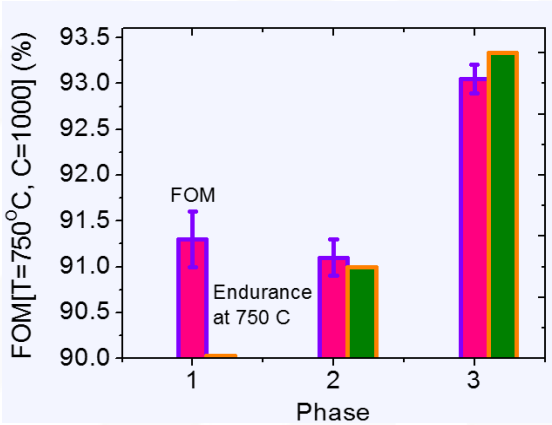



# A Long-Term Investment:
# Solar Selective Absorbers Continued…

$$FOM = \frac{\int_0^\infty (1 - R(\lambda)) I(\lambda) d\lambda - \frac{1}{C}\left[\int_0^\infty (1 - R(\lambda)) B(\lambda, T) d\lambda\right]}{\int_0^\infty I(\lambda) d\lambda}$$




| Sample | # of samples | Average FOM | Standard Deviation | P-value for FOM>Pyromark |
|---|---|---|---|---|
| 20 μm-thick $Cu_{0.5}Mn_{1.5}Fe_{0.5}O_4$ -silicone on Inconel 625 tube section, OD~76 mm, 40 day-night cycles | 4 | 750 C, C=1000<br>0.948, C=1000<br>(α=0.978 ±0.002; ε=0.489±0.002) | 750 C, C=1000<br>±0.002 | <0.001; |
| Pyromark 1/2020 | 5 | 750 C:<br>0.9006 for C=1000<br>(α=0.956±0.002; ε=0.892±0.002) | 0.002 for C=1000; | <0.0001 for FOM>0.87 |

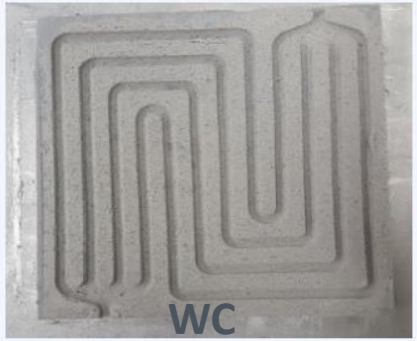



# A Long-Term Investment:
# Receivers & Heat Exchangers

Purdue University: Cermet Heat Exchangers for 800°C $scCO_2$

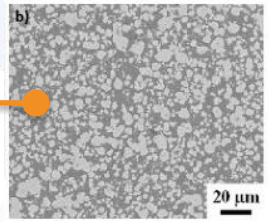
1. Develop Figures of Merit: Corrosion Rate; Average Failure Strength; Cost
2. Invest Over Time: 2015 CSP APOLLO-->2017 Gen3 CSP -->2018 FY18 FOA
3. Capture Innovation

$0.5Zr_2Cu(l) + WC(s) => ZrC(s) + W(s) + 0.5Cu(l)$

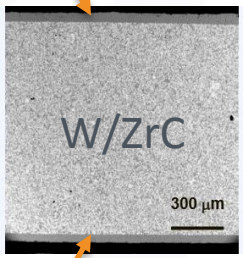



A fired, porous, rigid WC plate (15 cm x 15 cm x 1.4 cm) with a serpentine millichannel pattern and internal headers

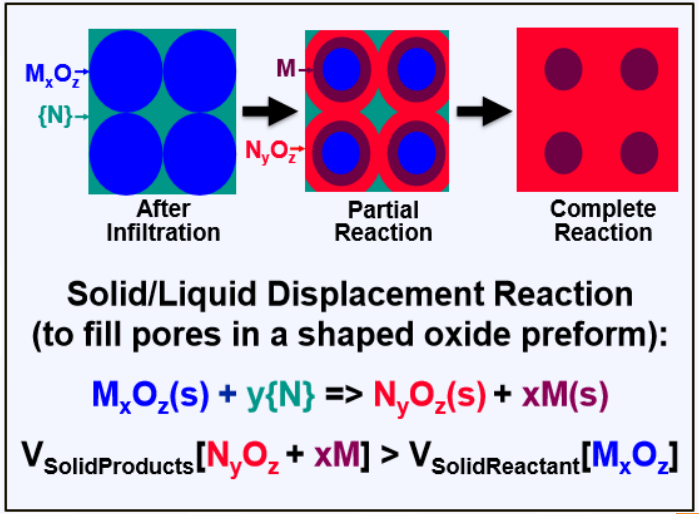
387 MPa +/- 22MPa fracture strength from 4 point bending at 800°C (ASTM C1211-13)




W/ZrC




W/ZrC --> coated W/ZrC -->$Cr/Al_2O_3$




Stamping --> roll-to-roll

# A Long-Term Investment: Additive Manufacturing

1. Develop Figures of Merit: Corrosion; Strength; Fracture Toughness; Thermal Cond.; Cost
2. Invest Over Time: 2018 FY18 FOA--> 2018 FY19-21 Lab Call-->…
3. Capture Innovation

## HEAT EXCHANGERS

### Traditional Alloys

**UC Davis**

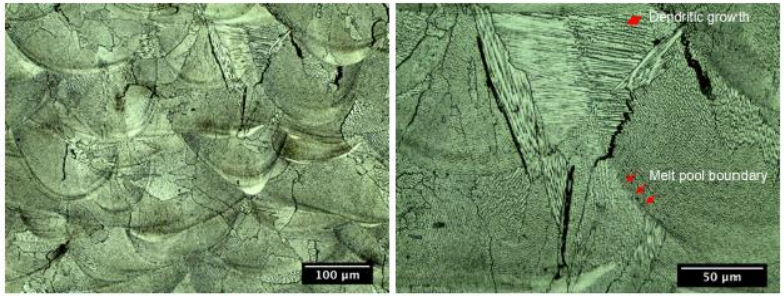
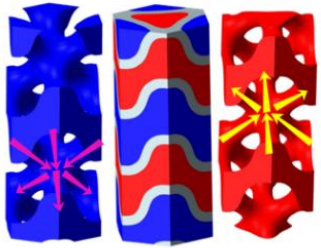



Figure 10. Optical micrographs showing the as-built microstructure and the solidification cracks on a Haynes 230 specimen #6 fabricated using 550 mm/s and 330 W.


**GE**



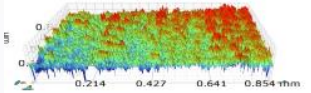
Fluid domains shown

### Ceramics

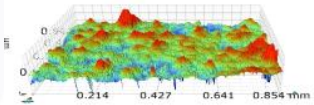
**Argonne National Lab**

Green Form SiC

Roughness




Sintered@1300C




Sintered@1380C

# Conclusions

- High-Temperature Thermal Systems: Part 2 seeks to diversify the portfolio by pursuing alternative markets/opportunities
- It's focused on advanced materials that might not fit into the Gen3 timeline. These materials are applied in Thermal Energy Storage systems, Receivers, and Heat Exchangers
- Diversified investments nurtured over the long-term can pay good dividends
- 'On-boarding' new tech starts with good scientific practices

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# Thank you!

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